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EFFECT OF THRUST AND ALTITUDE IN STEEP APPROACHES ON GROUND TRACK NOISE

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SUMMARY

A brief analysis was made of measurements of sound pressure level taken during approaches of a four-engine medium-range turbojet transport to determine the variation of sound pressure level with thrust and altitude for various glide slope angles. The sound pressure level data were obtained at four ground stations during 3° approaches with several flap deflections which provided variations in airplane drag and hence in the required thrust. The thrust required for stabilized flight on the 3° glide slope was computed from lift-drag polars available for the airplane for three flap deflections. By using the measured height of the aircraft above the four ground stations, the computed thrust, and the measured sound pressure level, the variation of sound pressure level with aircraft height and thrust for stabilized flight on 3° to 7° glide slopes was derived.

The results of the analysis indicated that by increasing the glide slope from 3° to 6°, the value of the sound pressure level could be reduced 11.5 to 14.0 dB, depending on the ground station location. Of this reduction, about 7.5 dB would be due to reduction in thrust and the remainder (4 to 6.5 dB), to increase in altitude. Values of sound pressure level computed on the basis of this analysis at one ground station for several steep approach profiles flown showed good agreement with sound pressure level measurements made during the steep approaches.

INTRODUCTION

Over the past several years, the NASA has been conducting research (refs. 1 to 3) to determine the problems associated with flying steeper than normal approaches to reduce the engine noise perceived along the ground track. In the early exploratory research such as reported in references 1 and 2, no measurements were made of the sound pressure level along the ground track of the approach path. In later research when turbojet and turbofan transports were introduced into the program (ref. 3), sound pressure measurements were made at several ground stations. Some of the first measurements indicated considerable variation in the sound pressure level at a given station due to pilot throttle activity for flight-path control. In some cases, it appeared that the reduction in noise level due to the steeper approach path was practically cancelled by the increase in thrust applied by the pilot for flight-path control. Because of the apparent large effect of thrust on the noise level, it appeared desirable to obtain a quantitative determination of the effect of altitude and thrust on the sound pressure level on the ground track. For the transport aircraft reported in reference 3, thrust was not measured; hence, a direct analysis of the effect of thrust and altitude on the sound pressure level could not be made. For one of the aircraft, however, lift-drag polars were available for three flap deflections. Since the tests included 3° approaches with these and other flap deflections, the lift-drag polars were used to compute the drag and hence the thrust required for the analysis of the sound pressure level measurements. The results of this analysis are presented herein.

SYMBOLS

γ glide slope angle

T total thrust required

δ_f flap deflection

$\Delta dB_{\Delta T}$ change in sound pressure level due to change in thrust, dB

$\Delta dB_{\Delta h}$ change in sound pressure level due to change in altitude, dB

AIRPLANE AND TESTS

Airplane

The airplane was a medium-range turbojet aircraft having the following characteristics:

Wing span	130.9 ft (39.9 m)
Wing area	2433 sq ft (226 sq m)
Maximum take-off weight	230,000 lb (104,300 kg)
Number of engines	4
Type of engines	Turbojet

The airplane was instrumented to measure control and throttle inputs, acceleration and angular velocity responses, speed of one engine, airspeed, and pressure altitude.

Tests

The steep approach program on this airplane included tests to measure the sound pressure level along the ground track in 3° approaches with various flap deflections which increased the drag of the airplane and hence the thrust required. Flap settings of 0°, 20°, 30°, 40°, and 50° were tested. Included in the program also were two-segment approaches – 5° into 3°, 7° into 3°, 8° into 3°, and 9° into 3° – transition being completed 1.5 statute miles (2414 meters) from the runway threshold. (For more detail on profiles and test conditions covered in the program, refer to airplane G in ref. 3.)

Measurements of sound pressure level were made along the ground track under the approach path at four stations – 1, 2, 3, and 5 statute miles (1609, 3219, 4828, and 8047 meters) from the threshold. The microphones were of the conventional condenser type, and had a frequency response flat to within ±3 dB over a frequency range of 20 cps to 12 000 cps. The microphones were located about 5 feet above ground level, the longitudinal axis being parallel to the ground and, generally, perpendicular to the vertical projection of the flight path. Aircraft height, lateral position, and range were measured with a precision radar (ref. 4).

RESULTS AND DISCUSSION

Flap Test Results

The results of the flap tests are shown in figure 1 as plots of sound pressure level in decibels against flap deflection for ground stations 1, 2, 3, and 5 statute miles (1609, 3219, 4828, and 8047 meters) from the runway threshold. Some scatter in the results is evident and is due in part to atmospheric conditions and different aircraft weights, but perhaps more to the level of thrust being applied for flight-path correction at the time of passage over a given ground station. To check on the latter premise, the sound pressure level for the 5-statute-mile (8047-meter) station was plotted in figure 2 against percent engine speed which is an index of engine thrust particularly, since all the flap tests were made within a $1\frac{3}{4}$-hour period and hence had essentially constant atmospheric conditions. The results of figure 2 show a consistent variation of the sound pressure level with percent engine speed with practically no scatter. It appears likely therefore that the scatter in the data of figure 1 is due to the level of thrust being applied by the pilot for flight-path correction as the aircraft passes over a given station.

Analysis of Flap Tests

In the following analysis, the assumption is made that the increase in sound pressure level with flap deflection is due to increase in thrust required as a result of the increase in airplane drag. The increase in aerodynamic noise due to flap deflection was neglected. On this basis, the drag of the airplane, and hence the total thrust required, was computed from lift-drag polars available for 0°, 30°, and 50° flap configurations by making use of the aircraft weight and airspeed and by assuming that the airplane was stabilized on a 3° glide slope (constant speed and no flight-path corrections). The plot of sound pressure level against the computed thrust required is shown in figure 3 for the four ground stations. The points were faired by straight lines having the same slope (8.6 dB/10 000 lb thrust; 19.4 dB/100 000 N) at the four stations inasmuch as this slope provided a reasonable fairing. Scatter about the faired line is very likely to be due to the level of thrust that was actually being applied for flight-path corrections which is not considered in the analysis.

With a further assumption that the primary differences in the sound pressure level at a given thrust for the different ground stations are due to aircraft height over the ground station, the sound pressure level from figure 3 was plotted against the average measured aircraft height for five levels of thrust required for stabilized flight on 3°, 4°, 5°, 6°, and 7° glide slopes for an aircraft weight of 165 000 lb (74 900 kg) at an approach speed of 126 knots. This variation of sound pressure level with altitude and thrust is shown in figure 4. (Note logarithmic scale on altitude.)

To illustrate the effect of reduced thrust and increase in altitude on the noise that can result from steep approaches, the curves for 3° and 6° in figure 4 are replotted in figure 5. Consider, for example, two single-segment approach paths, 3° and 6°, illustrated at the top of figure 5 which are typical of some single-segment approach paths used in the steep approach studies. If at the 2-statute-mile (3219-meter) station the altitude is increased from point a to point b and the glide slope was maintained at 3°, the reduction in the sound pressure level due to altitude would be about 4 dB. If at point b the thrust was reduced to allow stabilized flight on a 6° slope, there would be a further reduction in the sound pressure level of 7.5 dB. Thus, the overall reduction in sound pressure level due to altitude and thrust by flying the steeper approaches would be 11.5 dB. Similarly, at the 5-statute-mile (8047-meter) station (points c and d in fig. 5), the steeper approach would result in an overall reduction of about 14 dB of which 6.5 dB would be due to altitude and 7.5 dB, due to reduction in thrust.

Comparison With Measurements in Two-Segment Approaches

In figure 6, measured sound pressure levels are presented for 3° single-segment approaches and for two-segment approaches – 5° into 3°, 7° into 3°, 8° into 3°, and 9° into 3° – for two ground stations. The intercept of the steep slopes with the 3° slope occurred at about 1.5 statute miles (2414 meters). Also shown in figure 6 are curves estimated by using the results of figure 4, the nominal glide slope angle, and the aircraft altitude measured in the steep approach tests. The estimated curves are in reasonable agreement with measured values, when the effects of piloting technique are considered.

Actually, examination of the measured flight paths for nominal slopes of 5° and higher showed locally steeper slopes over the 5-statute-mile (8047-meter) station because of the overshoot during glide slope intercept. This overshoot was occasioned by the use of a flight director that was not tailored to intercept requirements for steeper than normal approaches.

CONCLUDING REMARKS

A brief analysis was made of measurements of sound pressure level taken during approaches of a four-engine medium-range turbojet transport to determine the variation of sound pressure level with thrust and altitude for various glide slope angles. The sound pressure data were obtained at four ground stations during 3° approaches with several flap deflections which provided variations in airplane drag and hence in the required thrust. The thrust required for stabilized flight on the 3° glide slope was computed from lift-drag polars available for the airplane for three flap deflections. By using the measured height of the aircraft above the four ground stations, the computed thrust, and the measured sound pressure level, the variation of sound pressure level with aircraft height and thrust for stabilized flight on 3° to 7° glide slopes was derived.

The results of the analysis indicated that by increasing the glide slope from 3° to 6° the value of sound pressure level could be reduced 11.5 to 14.0 dB, depending on the ground station location. Of this reduction, about 7.5 dB would be due to reduction in thrust and the remainder (4 to 6.5 dB) to increase in altitude. Values of sound pressure level computed on the basis of this analysis at one ground station for several steep approach profiles flown showed good agreement with sound pressure level measurements made during the steep approaches.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 10, 1967,
126-62-03-03-23.

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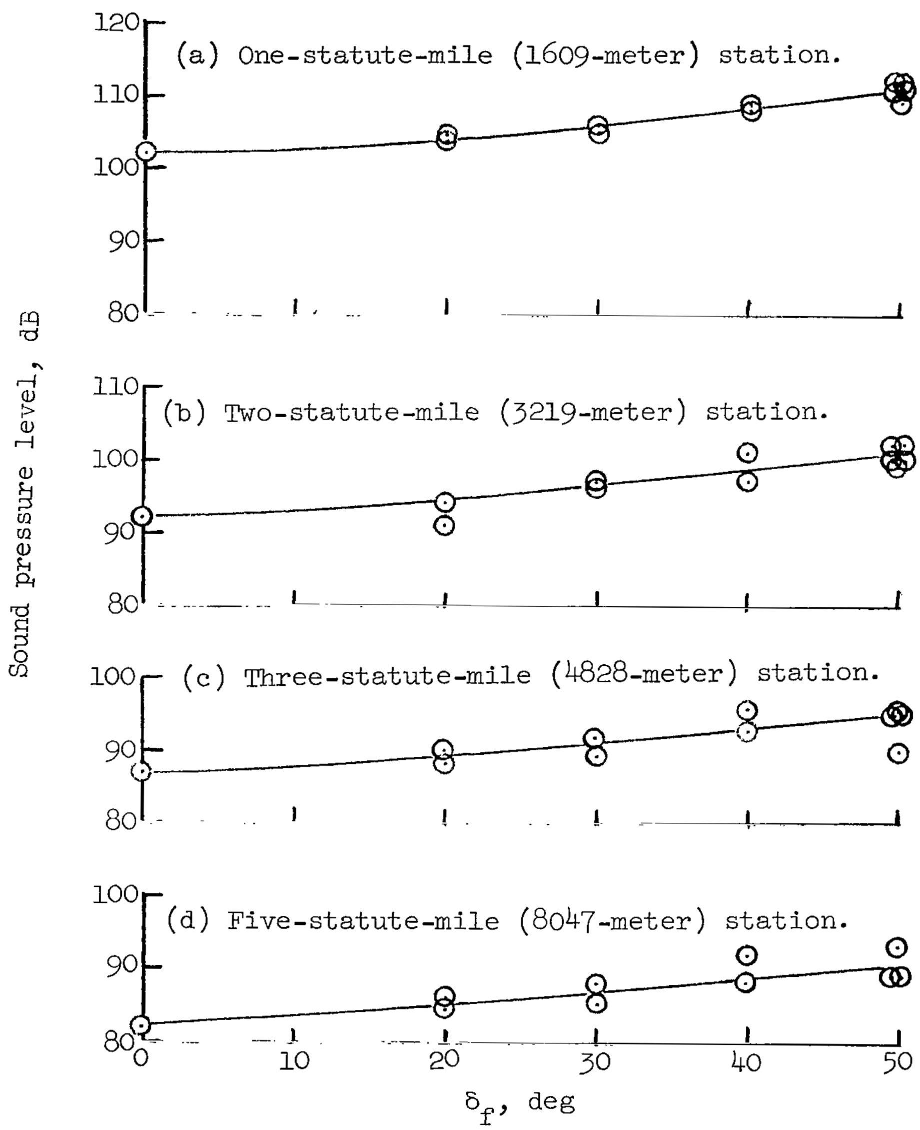


Figure 1.- Variation of sound pressure level with flap deflection at four ground stations. Glide slope 3°.

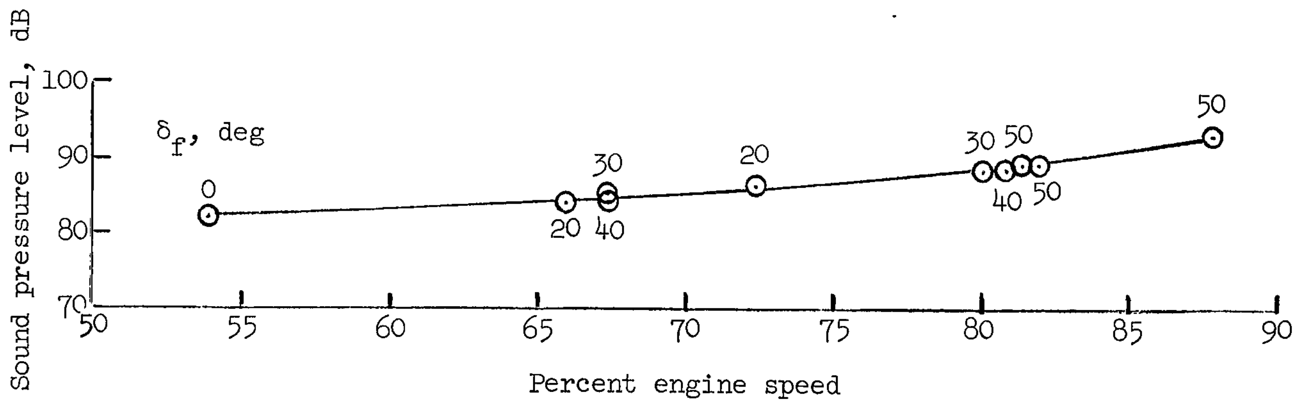


Figure 2.- Variation of sound pressure level with engine speed for various flap deflections. Glide slope 3°. Five-statute-mile (8047-meter) ground station.

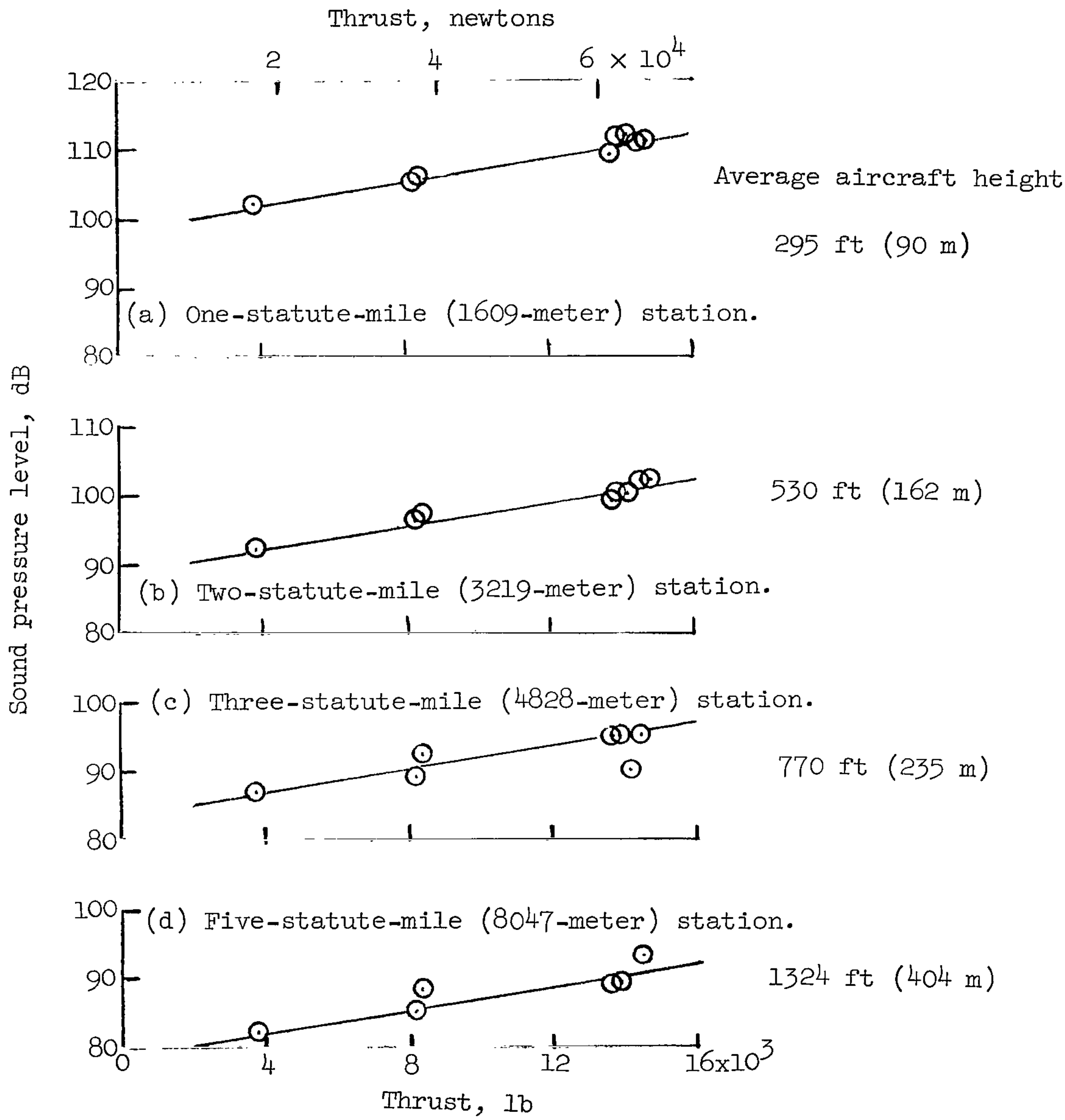


Figure 3.- Variation of sound pressure level with calculated thrust at four ground stations. Glide slope 3°.

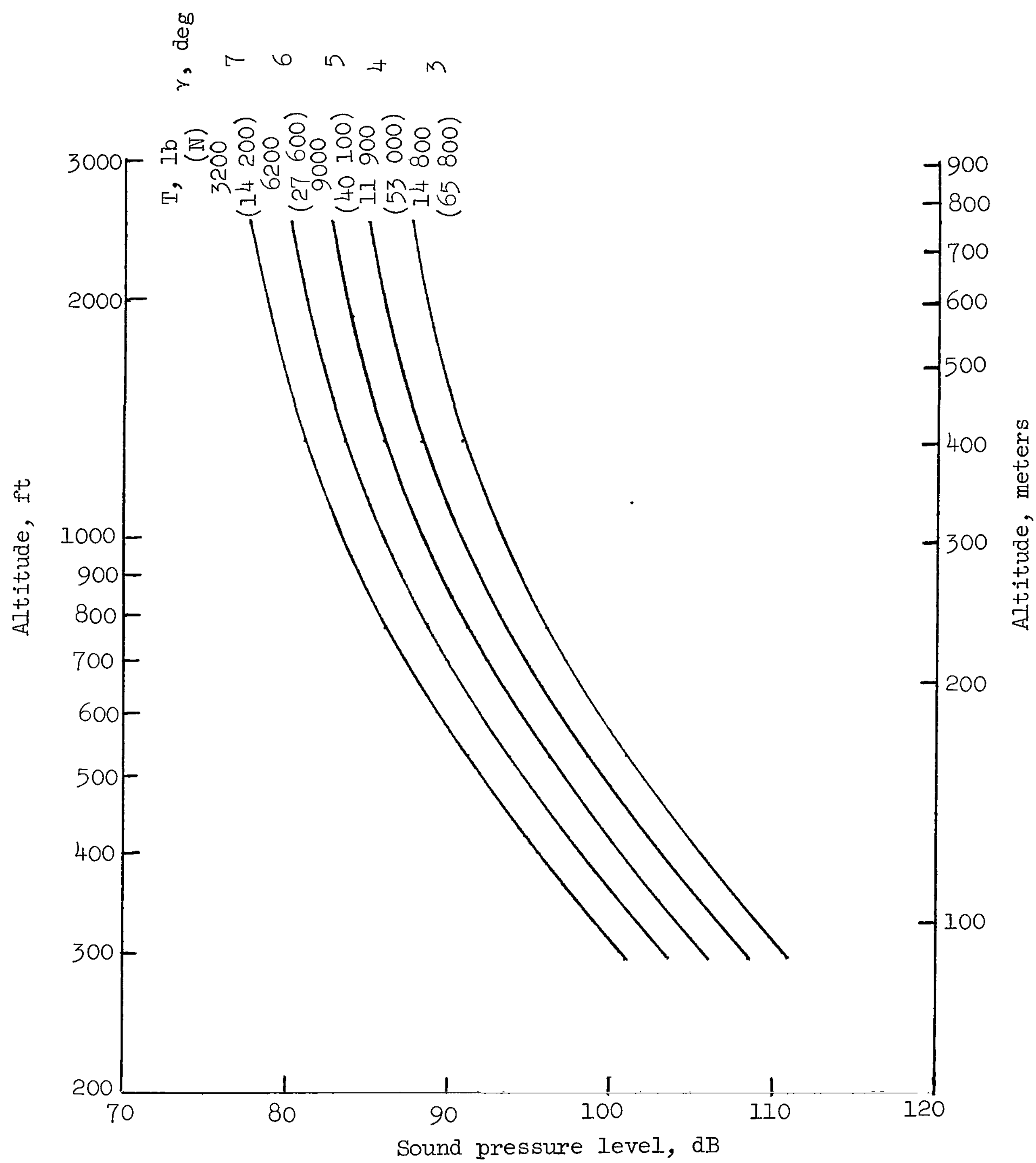
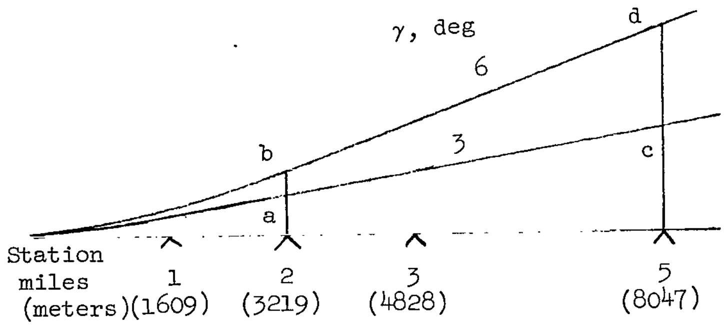
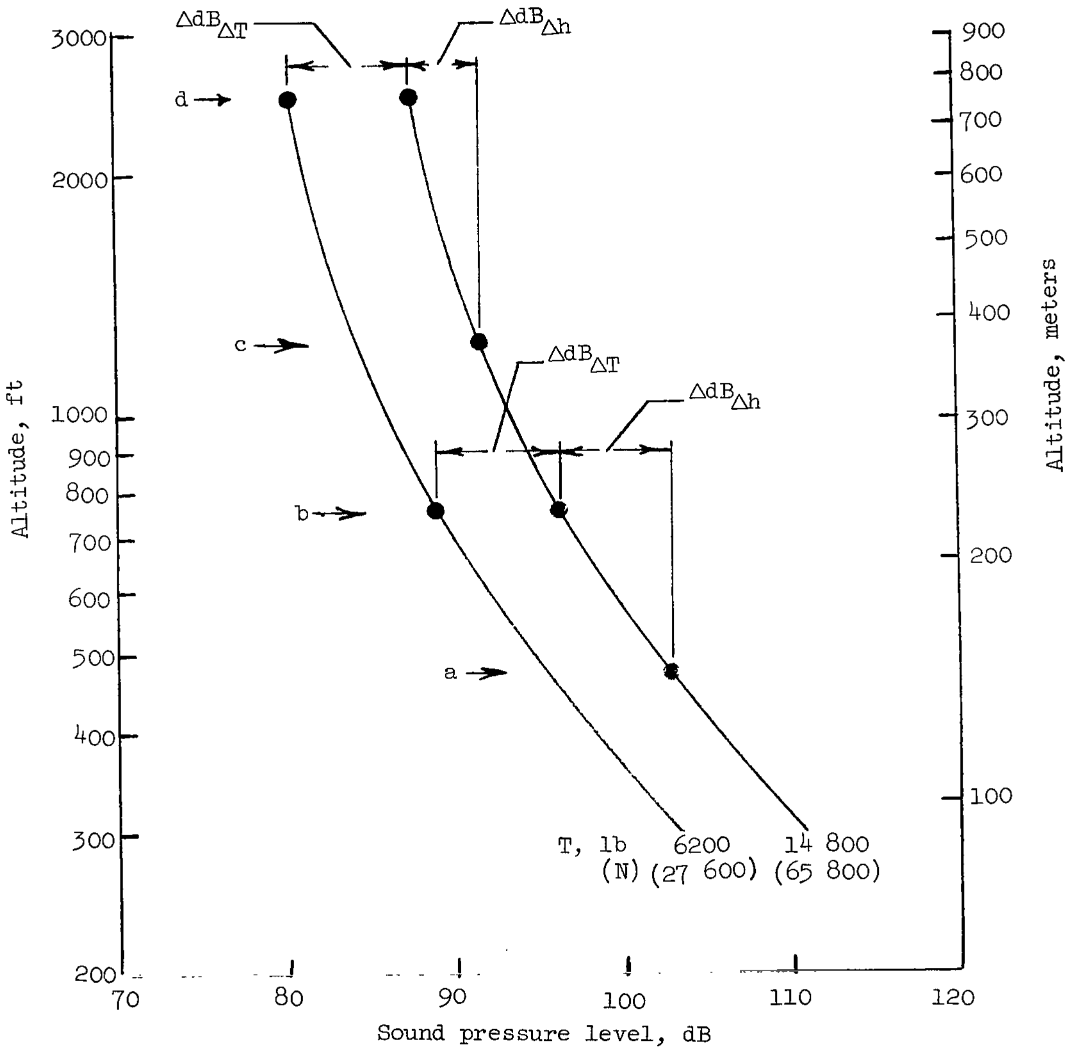


Figure 4.- Variation of sound pressure level with altitude and thrust. Aircraft weight, 165 000 pounds (74 900 kg); approach speed, 126 knots.



(a) Single-segment profiles.



(b) Sound pressure level variation with altitude for two levels of thrust.

Figure 5.- Illustration of effect of altitude and thrust on sound pressure level for 3° and 6° single-segment profiles. (Curves from fig. 4.)

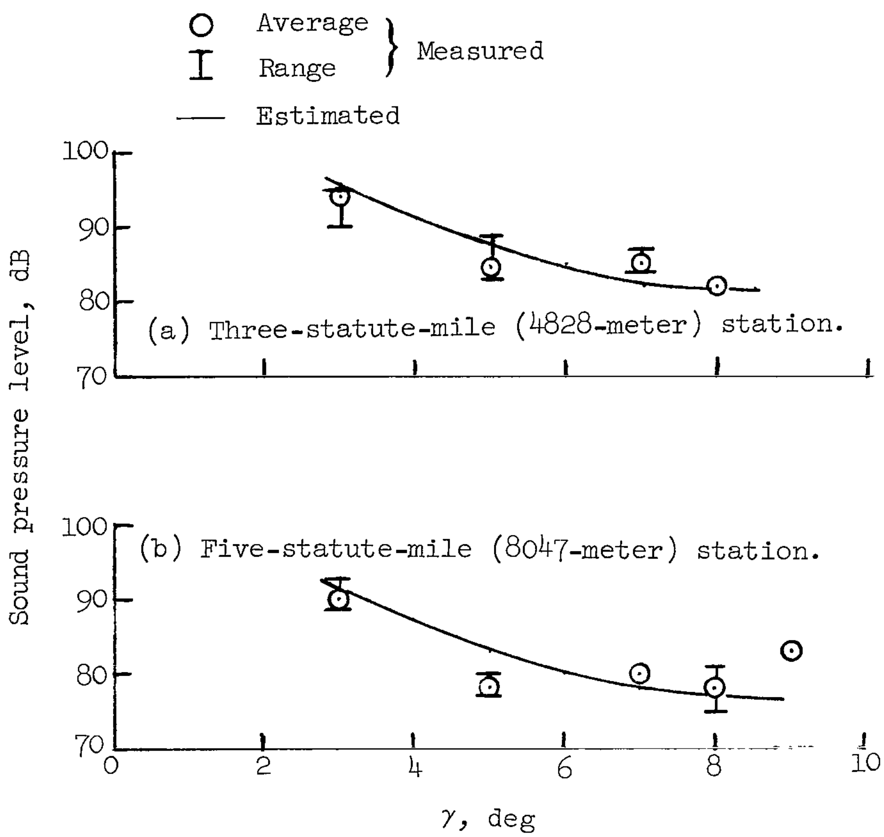


Figure 6.- Comparison of measured and estimated sound pressure levels. Except for 3^0, the values at other angles are for two-segment approaches with intercept at 1.5 statute miles (2414 meters) from runway threshold. $\delta_f = 50^0$.

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